Table 24 – Linearity of the D/U ratio (LTE signal centered at 702.5 MHz)

DTV Model		Sensitivity +1 dB	Sensitivity +2 dB	Sensitivity +3 dB	Sensitivity +6 dB	-68 dBm	-53dBm
LG - 42LK450	TOV-A	-39.5	-42.5	-42.5	-44.5	-46.0	-45.0
	TOV-D	-39.5	-42.5	-42.5	-44.5	-46.0	-45.0
	Level at DTV input (dBm):	-46.0	-42.0	-41.0	-36.0	-22.0	-8.0
		TOV-D sensitivity -86.5 dBm					
		LTE Signal - BW 3 MHz, 1RB, Center Frequency 702.5 MHz					
		All power readings are dBm values at the DTV input, all D/U ratios are dB values					

Table 25 – Linearity of the D/U ratio (LTE signal centered at 701.5 MHz)

DTV Model		Sensitivity +1 dB	Sensitivity +3 dB	-68 dBm	-53dBm
LG - 42LK450	TOV-A	-36.4	-43.4	-46.2	-46.2
	TOV-D	-37.5	-43.5	-45.1	-46.2
Panasonic - VIERA TC-L32C3	TOV-A	-41.0	-43.0	-43.9	-43.8
	TOV-D	-41.2	-42.8	-44.0	-43.8
Samsung - LN37D550	TOV-A	-43.0	-49.2	-48.8	-48.0
	TOV-D	-43.5	-49.2	-48.0	-48.0
Sony - BRAVIA KDL46NX720	TOV-A	-46.3	-49.1	-51.1	-51.0
	TOV-D	-46.5	-49.4	-51.0	-51.0
Toshiba - 24SL410U	TOV-A	-41.4	-41.2	-44.8	-44.0
	TOV-D	-41.2	-41.2	-45.2	-44.0
		LTE Signal - BW 5 MHz, 1RB, Center Frequency 701.5 MHz			
		All D/U ratios are in dB			

Table 26 – TOV Levels 1 dB over threshold of the DTV and 3 MHz LTE UE signal

Manufacturer	M/N	Description	TOV-D	TOV-A
LG	42LK450	42-Inch 1080p 60 Hz LCD HDTV	-37.2	-35.8
Panasonic	VIERA TC-L32C3	32-Inch 720p LCD HDTV	-43.9	-44.0
Samsung	LN37D550	37-Inch 1080p 60Hz LCD HDTV	-45.6	-45.4
Sony	BRAVIA KDL46NX720	46-inch 1080p WiFi 3D LED HDTV	-46.7	-46.5
Toshiba	24SL410U	24-Inch 1080p 60 Hz LED-LCD HDTV	-43.6	-43.5
		DTV signal at 1 dB over the DTV threshold of sensitivity LTE UE signal is 3 MHz bandwidth centered at 702.5 MHz		

Table 27 – TOV Levels 1 dB over threshold of the DTV and 5 MHz LTE UE signal

Manufacturer	M/N	Description	TOV-D	TOV-A
LG	42LK450	42-Inch 1080p 60 Hz LCD HDTV	-37.5	-36.4
Panasonic	VIERA TC-L32C3	32-Inch 720p LCD HDTV	-41.2	-41.0
Samsung	LN37D550	37-Inch 1080p 60Hz LCD HDTV	-43.5	-43.0
Sony	BRAVIA KDL46NX720	46-inch 1080p WiFi 3D LED HDTV	-46.5	-46.3
Toshiba	24SL410U	24-Inch 1080p 60 Hz LED-LCD HDTV	-41.2	-41.4
		DTV signal at 1 dB over the DTV threshold of sensitivity LTE UE signal is 5 MHz bandwidth centered at 702.5 MHz		

7.4 LTE Waveform evaluation

This evaluation was intended to determine impact on TOV levels variations in the LTE waveform can have. LTE transmissions can vary in a number of ways. The primary test loop used what is assumed to be a worst case selection of waveform variables. This evaluation followed the procedure described in Section 7.2 but with variations of the LTE waveform being explored.

The primary variable found to impact the TOV level was the number of resource blocks used. The effect was to concentrate the signal power within the active resource blocks. Testing was performed with the minimum, one resource block, and the maximum resource blocks for each bandwidth. The maximum number of resource blocks is as follows:

- 1.4 MHz bandwidth – 6 resource blocks maximum
- 3.0 MHz bandwidth – 15 resource blocks maximum
- 5.0 MHz bandwidth – 25 resource blocks maximum

The general trend was that use of the maximum resource blocks was the worst case condition, Figure 33.

7.5 Strong Signal evaluation

There are two types of strong signal interference. The first category occurs when a strong signal reduces the sensitivity of the DTV receiver. This is called the brute-force-overload (BFO) problem. The second category is intermodulation (IM), which can occur when strong DTV and LTE signals are both present and create intermodulation products that in turn cause interference to weaker and more distant DTV signals.

Testing was done under strong signal conditions, -28 dBm of DTV signal power. In early testing interference with the LTE base station simulator occurred and required filtering and increased separation between the DTV transmitting antenna and the LTE base station to prevent interference to the LTE link.

Most of the high signal level testing was performed by conducted means because it was easier to achieve higher signal levels and because it was easier to isolate parts of the system, insuring that the test was of the DTV receiver's performance and not inadvertently of other equipment in the test setup. It was found that there is a degradation of D/U ratios under strong signal conditions, Figure 33. However, at levels that are achievable in actual use, no inordinate strong signal mechanism manifested themselves, other than the degradation of D/U ratios.

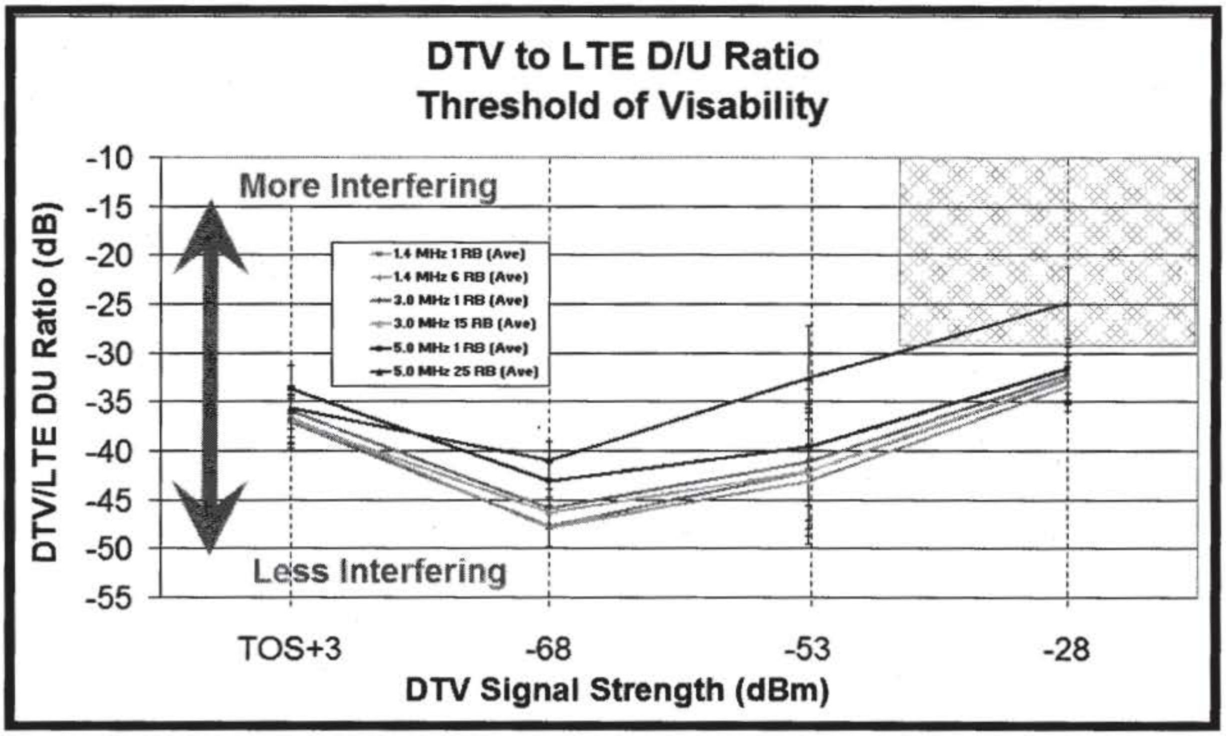

Figure 33 – Variation in D/U Ratio as a function of DTV Signal Strength

Section 8 Findings & Observations

8.1 Comparison of Conducted and OTA

To compare the conducted to OTA test results and to estimate threat distances, meaning the distance at which an LTE UE is capable of causing interference, a path loss model is needed. For closer distances line of sight and indoor models are most appropriate. For the frequencies of interest in this study the wavelength, λ, is about 0.4 m. The potential for near field effects to become significant must be considered for distances closer than 0.8 m or 2 λ. A line of sight model is believed most appropriate for distances up to 3 m. For distances between 3 and 30 m it is probable that there are intervening walls, furniture and influence of other objects in the environment. Reflections and multipath also become more significant. Most of the measured threat distances were found to fall in the near field to 30 m range[22] and a line of sight model with some assumption of architectural influence beyond 3 m is believed appropriate.

The guidance of IEEE 1900.2 is helpful on this issue:

A.2 Scale

The appropriate model depends on the communication distances. Indoor models are used when the use case is an indoor environment, involving walls and other common features of buildings. Outdoor models are used for communications over several kilometers. Most propagation models specify ranges over which they are appropriate. Communication in the near-field is defined as distances less than approximately $2D^2/\lambda$ where D is the largest dimension of the antenna (not including the antenna mounting), and λ is the wavelength. The near-field is typically within one wavelength of the transmitter. However, it may be important for some applications such as RFID readers where the wavelength is long and communication distances are short. The rate of change varies widely in the near-field vary based upon the characteristics of the transmitting antenna and other variables. Beyond the near-field signals generally propagate using free-space propagation whereby the received signal is proportional to the inverse of the distance squared.

The free-space region is where the propagation does not have significant interaction with the ground or surrounding objects. Consider the line connecting a transmitter and receiver of length d. The first Fresnel zone is the ellipse with foci at the transmitter and receivers such that the distance from the transmitter to any point on the ellipse and on to the receiver is $d+\lambda/2$. As long as objects do not intersect this ellipse, the attenuation can be considered as line of sight and attenuating as in free space.[23] For example, assuming two antennas over a flat surface, the ellipse will touch the ground when:

$$d > d_f = \frac{4h_{tx}h_{rx}}{\lambda} \qquad (1)$$

where h_{tx} and h_{rx} are the height of the transmitter and receiver above the ground. If the ground is not flat then a careful analysis would need to show if any portion of the ground intersects the first Fresnel ellipse. Beyond d_f, the path-loss is typically much worse than free space. If the line-of-site path from transmitter antenna to receiver is obstructed then other variables come into play, depending on the obstructions.[24]

The path loss equation for a line of sight model is:

---

[22] Testing was performed to 10 m. Where interference occurred at 10 m, the threat distance was extrapolated from the 10 m measurements.

[23] The assumption of having a line of sight (LOS) channel if the first Fresnel zone is not obstructed is only true for antenna systems having a circular aperture. If one uses omnidirectional antennas, a (reflecting) object right behind the transmitter may cause deep fades. However, this is not typical for LOS environments.

[24] IEEE 1900.2, "Recommended Practice for the Analysis of In-Band and Adjacent Band Interference and Coexistence Between Radio Systems", Annex A.2.

Link Budget Equation
(Line of Sight)

$$P_{RX} = P_{TX} + G_{TX} - L_{TX} - L_{FX} - L_{M} + G_{RX} - L_{RX}$$

P_{RX} - Receive Power (dBm)

P_{TX} - Transmit Power (dBm)

G_{TX} - TX Antenna Gain (dBi)

L_{TX} - Transmitter Losses (VSWR, connectors…)

L_{FX} - Path Loss (dB) $L_{FX}(dB) = 20\log(d) + 20\log(f) - 27.55$ **(where d is in m & f is in MHz)**

For f = 701 MHz $L_{FX}(dB) = 20\log(d) + 29.36$ **(where d is in m)**

For f = 701 MHz and d = 1 m $L_{FX}(dB) = 29.36$

L_{M} - Miscellaneous Losses (polarization mismatch, body loss, fading margin…..)

G_{RX} - RX Atennan Gain (dBi)

L_{RX} - Receiver Losses (VSWR, connectors…)

The predicted path loss estimated, without assuming any architectural influences was:

P_{TX}	RF TX Power (Watts)		0.2 W
	RF TX Power (dBm)		23.0 dBm
L_{TX}	TX VSWR Loss		0.0 dB
L_{RX}	RX VSWR Loss		0.0 dB
L_{FX}	Path Loss @ 1 m		29.4 dB
G_{TX}	TX Antenna Gain		0.0 dBd
G_{RX}	RX Antenna Gain		0.0 dBd
	Cross Polarization		0.0 dB
	Antenna Misalignment		0.0 dB
	Antenna Factor		13.8 dB
	DTV Cable & XFMR Loss		5.4 dB
	Unidentified Loss		0.0 dB
L_M	Total Miscellaneous Losses		19.2 dB
	TOTAL Link Loss	1 m	48.5 dB
		3 m	58.1 dB
		6 m	64.1 dB
		10 m	68.5 dB
	Expected RX Power at DTV from full 23 dBm TX Pwr	1 m	-25.5 dBm
		3 m	-35.1 dBm
		6 m	-41.1 dBm
		10 m	-45.5 dBm

8.2 Selection of Units for OTA

From the full set of DTV receivers tested three of the worst performers and two average performers were selected for more detailed testing and verification of the conducted testing by actual over-the-air testing. This set of consumer-grade receivers was selected to bring focus to receivers performing at the mid-range and at the lower end of the tested DTV sets. However, when their results were computed separately from the full population of DTV receivers tested the average and standard deviation changed little, as shown in Table 28. The comparisons for OTA tests, inside an anechoic chamber and using other LTE UE devices as the source of the interfering signal is to this subset of DTV receivers and is believed to be a fair predictor of the full set of 26 DTV receivers.

Table 28 – Difference in Values and Standard Deviation Between the Full DTV Set and Those Selected for OTA Testing

Delta between full set and OTA DTV units					
		LTE Signal Strength at DTV Threshold of Visability (dBm)			
		DTV Signal Strength (dBm)			
Signal Bandwidth & Resource Blocks		TOS+3	-68	-53	-28
	Value for	-82	-68	-53	-28
1.4 MHz 1 RB	Ave	0.7 dB	0.5 dB	0.0 dB	0.6 dB
1.4 MHz 6 RB	Ave	-1.5 dB	-0.3 dB	0.2 dB	0.3 dB
3.0 MHz 1 RB	Ave	1.0 dB	0.4 dB	1.1 dB	1.0 dB
3.0 MHz 15 RB	Ave	-0.9 dB	0.3 dB	0.2 dB	0.6 dB
5.0 MHz 1 RB	Ave	-1.4 dB	0.5 dB	1.2 dB	1.3 dB
5.0 MHz 25 RB	Ave	0.0 dB	-1.3 dB	-0.7 dB	1.0 dB

Delta of Standard Deviations					
		LTE Signal Strength at DTV Threshold of Visability (dBm)			
		DTV Signal Strength (dBm)			
Signal Bandwidth & Resource Blocks		TOS+3	-68	-53	-28
	Value for	-82	-68	-53	-28
1.4 MHz 1 RB	Ave	-0.7 dB	-1.8 dB	-3.3 dB	-1.7 dB
1.4 MHz 6 RB	Ave	-0.1 dB	-1.7 dB	-1.8 dB	-1.5 dB
3.0 MHz 1 RB	Ave	0.4 dB	-1.8 dB	-1.8 dB	-2.0 dB
3.0 MHz 15 RB	Ave	0.2 dB	-1.3 dB	-1.2 dB	-1.7 dB
5.0 MHz 1 RB	Ave	7.4 dB	-1.5 dB	-1.7 dB	-2.0 dB
5.0 MHz 25 RB	Ave	2.7 dB	-1.2 dB	-2.5 dB	-1.6 dB

Extensive testing was performed on the units selected for OTA evaluation. The units were tested in a 3 m anechoic chamber. For distances that exceeded 3 m, additional tests were conducted in a 10 m semi-anechoic chamber. In addition to the BandRich Model C525, a Samsung R930, a Band Class 12 device and a Samsung Note, a Band Class 17 device, were used as signal sources. The Band Class 17 device was included to provide a comparative reference to an LTE UE operating in the next adjacent channel (former TV Channel 53). The additional LTE UEs were also tested conducted, to provide additional points of comparison. That is, the desired DTV signal and undesired LTE sign were physicaly connected to the DTV receiver input using the appropriate coaxial cables, combiners, and matching transformers. Access to the LTE UE RF output power was achieved using RF testing port of the device.

OTA testing was performed using 3 LTE UEs as interferers, the BandRich C525 USB dongle, a Samsung R930, both Band Class 12 devices and a Band Class 17 device operating in the next adjacent channel, a Samsung Note. The threat distances measured OTA were somehwhat higher than those predicted from the conducted data. However, the differences were within the measurement uncertainty.

8.3 Interference Distances

Significant effort was invested in understanding the differences between the predicted threat distances from the conducted data and that found by OTA testing. One factor that clearly contributed to the difference is that in the OTA testing, even though it was performed in an anechoic chamber, there were some reflections which degraded the DTV signal, shown in an increase in the Error Vector Magnitude (EVM). If the DTV receivers were given degraded signal quality, even though the signal amplitude was the same, an increase in sensitivity to interference is to be expected.

In the OTA testing the LTE UE were operating at the maximum transmitter power and some increase in spectrum splatter is common when units operated at the limit of their capability. It is believed that this was also a factor.

However, not withstanding those differences, it must be remembered that the threat distances are being reported in linear units, meters, but the dynamics of this interference are fundamentally logarithmic. When viewed logarithmically the differences in threat distances are generally within 6 dB, or within a factor of two from each other. Figure 34 through Figure 37 presents a summary of the threat distances measured for the differing methods and LTE UE devices used in this project.

As can be seen in the values reported in Figure 34 through Figure 37, the risk of interference for DTV signals at or above a received signal level at the receiver's F-fitting input of -68 dBm is low. The trend from -68 dBm to TOS was explored and the results were found to extrapolate reasonable well with some increased sensitivity to interference as TOS was approached.

When distances > 10 m are reported in the TOS+3 estimates, these are extrapolated from the levels measured at 10 m, in the 10 m semi-anechoic chamber.

What can be observed is that the threat distance decreases as the frequency guard band increases. The threat distances found for 1.4 and 3.0 MHz wide signals in the former TV channel 52 (now the 700 MHz A block) are roughly comparable to that measured with a 5 MHz signal in the former TV channel 53 band.

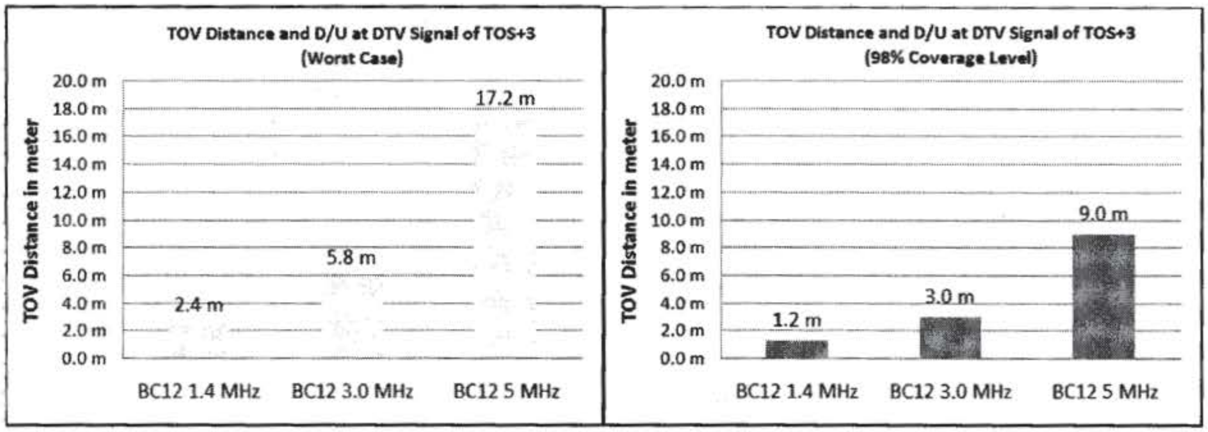

Figure 34 – Comparison of Average Threat Distances – DTV Signal Level – TOS + 3 dB

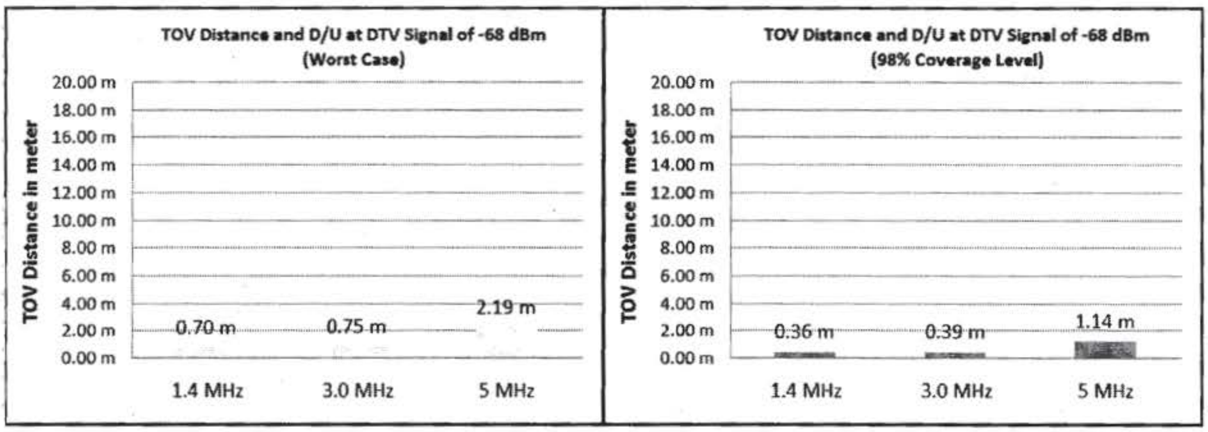

Figure 35 – Comparison of Average Threat Distances – DTV Signal Level – -68 dBm

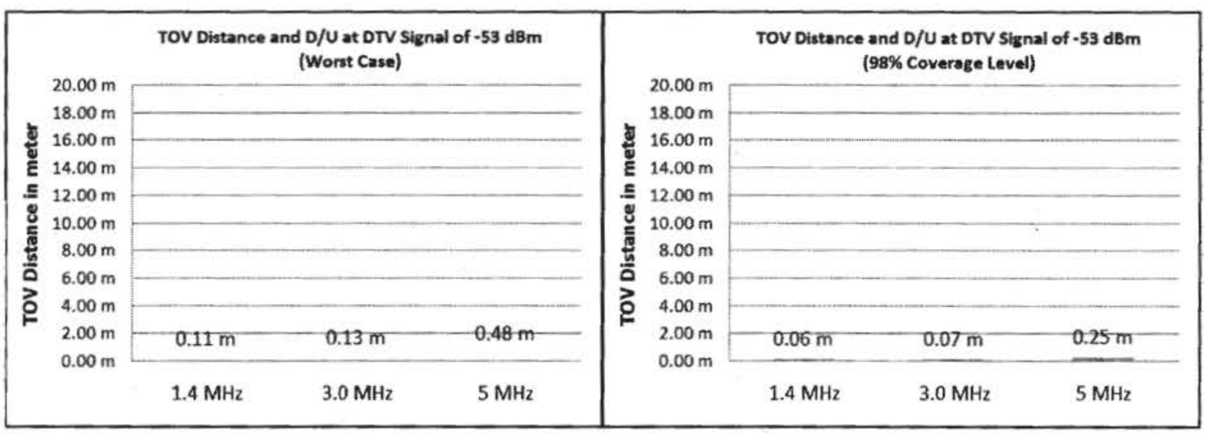

Figure 36 – Comparison of Average Threat Distances – DTV Signal Level – -53 dBm

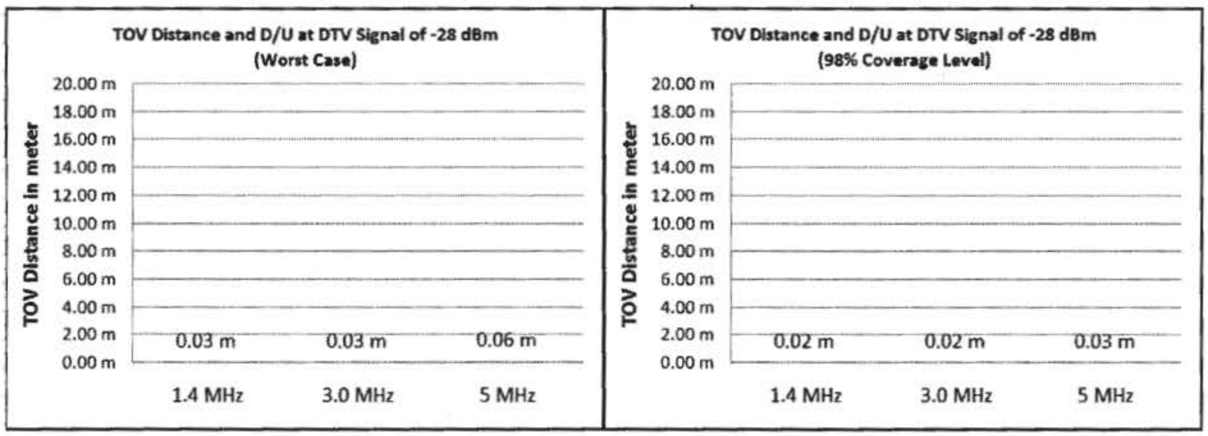

Figure 37 – Comparison of Average Threat Distances – DTV Signal Level – -28 dBm

Section 9 Field Performance

This section analyzes the field performance to be expected, based on the laboratory test results obtained. Laboratory tests determine the conditions under which interference is likely to occur. With this understanding the actual field experience may be predicted.

The findings reported are based on multiple tests and differing approaches to testing. Measurement of the OOBE from LTE UE predicts interference levels, if OOBE falling into Channel 51 is the dominant interference factor. This was found to be generally true and as a result the OOBE measurements generally predict the tolerance of DTV receiver's to the presence of an LTE signal. Conducted measurements were performed using both an LTE signal simulator and commercially available LTE UE devices. OTA measurements, again using multiple LTE UE, were performed. The results of these tests resulted in 4-6 independent estimates of the tolerance of DTV receivers to LTE UE operating in the 698-704 MHz band. These estimates were found to be in general agreement and consistent. However, particularly in the weaker signal regions variance was observed between devices and with test-to-test repeatability. This variance is shown as error bars on the data in the various graphs presented.

When extending the laboratory tests to predict field experience a number of new variables come into play. Some of the variables controlled in the laboratory become uncontrolled in the field. A review of the significant variables includes:

1. DTV Signal Variables
    a. DTV Signal Amplitude – The DTV signal will vary by location and will also vary in the same location due to changes in the propagation path.
    b. DTV Signal Quality – The quality of the DTV signal will vary with changing multipath conditions.
2. LTE Transmission Received by DTV
    a. LTE UE TX Power – The LTE network aggressively controls the transmit power of active UE devices, changing their transmit power as often as every millisecond. LTE UE devices will be kept at the lowest power at which communication quality can be maintained, which means that LTE UE devices will operate at or near their maximum power relatively rarely.
    b. LTE Resource Blocks Used – The LTE system assigns 180 kHz wide resource blocks as needed to support the needs of the communication session in progress. An LTE UE with more resource blocks will have a broader signal than one with fewer resource blocks. The number of resource blocks and their position within the LTE channel, whether the signal is closer to or more distance from the DTV channel, impacts the interference potential.
    c. Separation Distance – The separation distance between the DTV antenna and LTE UE is a primary variable in determining the amount of LTE transmission power received by the DTV.
    d. Relative Antenna Position – Both the DTV and LTE UE antennas have directional patterns. The relative position of the two antennas significantly influences how well or poorly the LTE signal is received by the DTV.
    e. Relative Antenna Orientation – The DTV and LTE UE antennas are linearly polarized and to the degree they are cross polarized the signal reception will be degraded from what is possible when they are oriented and positioned for maximum reception.
    f. Ratio of LTE UE TX Power to OOBE – LTE UE OOBE were found to be a first order cause of interference. Accordingly the level of the OOBE, relative to the LTE UE TX power, is significant. Any factors that increase the OOBE arriving at the DTV will significantly influence the interference picture.
3. RF Propagation Environment
    a. Architectural Influence - When there is any significant separation distance and almost universally if the distance is greater than 3 m, there will be walls, furniture or other objects influencing the RF propagation from the LTE UE to the indoor DTV receiving antenna. Architectural influence on the LTE UE signal must be considered for distances over 3 m and can be a factor for shorter distances.

   b. Multi-Path - Reflections, creating multiple signals, arriving at the DTV antenna with varied phase relationships, can both enhance or degrade the signal. If people or objects are moving in the environment, the reflective environment will be changing, creating a dynamic signal environment.

4. Temporal Variables

   a. Usage - The most significant temporal variable is usage. For interference to occur the LTE UE must be transmitting and someone must be watching TV.

   b. TV Picture Content – DTV receivers are highly sophisticated and able to adapt to noisy signals. If the picture is relatively static, with little motion, the signal processing can correct missing data, filling in unchanged parts of the picture. Pictures with complex motion are more demanding and as a result make the DTV more susceptible to interference, because it is far less able to correct for lost portions of the signal.

All of these variables impact the degree of LTE interference on DTV reception. Laboratory testing measures the degree each variable impacts the potential for interference. In actual experience these variables will change for different locations and typically will be dynamically changing in any give location. The result is that while the worst case condition created in the laboratory is possible, it has a low probability of being created in actual experience. The actual use experience will be a probability distribution in which for some percentage of locations and some percentage of the time interference is probable and for other locations and times interference is improbable. The challenge of the analysis is to accurately represent these relative probabilities.

As the IEEE 1900.2 standard points out, whether a given probability of interference is acceptable or unacceptable is a public policy value judgment and not a technical determination. Most would agree that at some low probability of interference the value to society is best served by having both services in operation. Conversely, most would also agree that at a higher probability of interference the DTV signal should be protected or the potential for interference mitigated in some other way.

The remainder of this section will quantify the potential for interference to DTV reception from an LTE UE operating in the adjacent frequency band.

9.1 LTE Power Control

LTE UE is limited in the 3GPP standards to 23 dBm transmitter power output (TPO). This defines the worst case radiated power level and 23 dBm was used in the testing when estimating the worst case interference distance. As mentioned, LTE uses aggressive power control, keeping LTE UE transmitters at the lowest power level consistent with reliable communication. An LTE UE will only operate at 23 dBm or a power close to that when its signaling conditions do not allow reliable communication at lower levels.

A further consideration is that the 23 dBm TPO allowed by the 3GPP specifications is measured at the input to the LTE UE device's transmitting antenna. Mismatch and other losses related to the antenna will prevent LTE UE from achieving a full 23 dBm of radiated power, especially for a band edge A block device. A contrary factor is that there typically will be 2 to 3 dB of antenna gain. Currently the best device found on the market had a Total Radiated Power (TRP) of 20.5 dBm, with the peak point in the pattern at 23.9 dBm ERP. Most devices currently on the market were found to be 4 to 6 dB below these levels.

The DTV transmit tower and LTE base stations will not have a fixed relationship to each other and therefore the coincidence of low DTV signal strength and poor LTE signal conditions, requiring maximum power transmission, will only occur in a subset of locations. As shown in Figure 38, a possibility of interference only exists in those areas where the DTV signal is weak and the LTE UE is transmitting near its maximum power. As the figure also makes clear, LTE network design and placement of the LTE basestations can have a significant impact on the size and location of these areas.

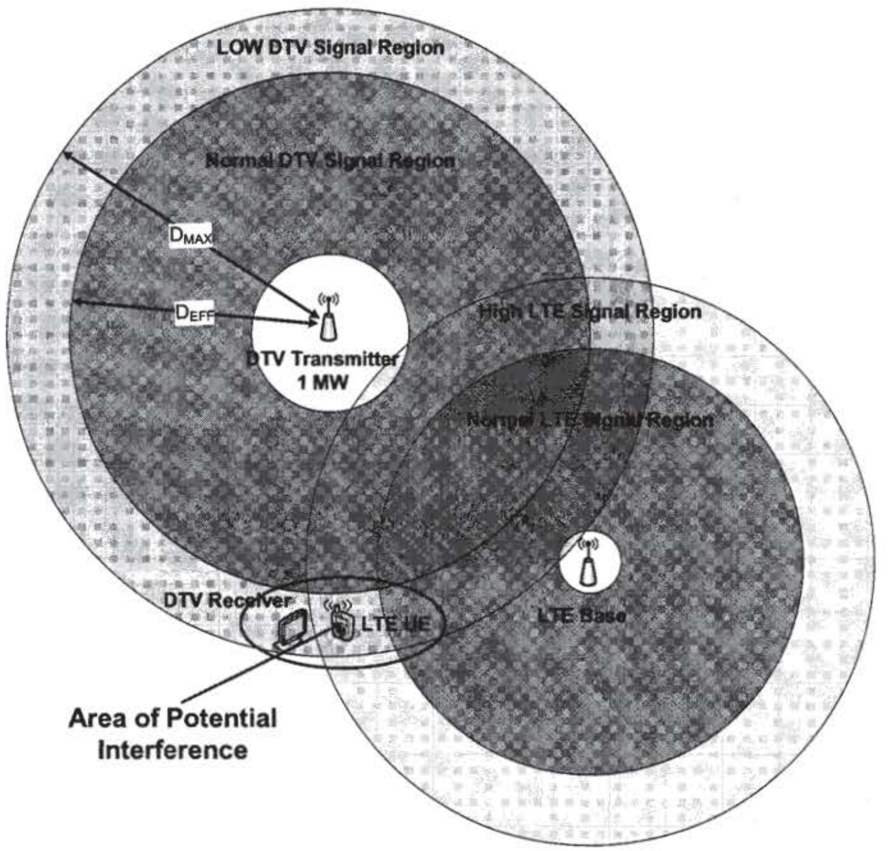

Figure 38 – The probability of LTE to DTV interference is highest where the DTV signal is weak and the LTE UE is transmitting at its maximum power. In other regions the probability is much less and often virtually non-existent.

9.2 Relative Antenna Position & Orientation

Both DTV and LTE UE antennas have directional patterns with significant variation in them. The testing performed in this project sought to maximize the coupling between antennas by placing and aligning the antennas for maximum coupling of LTE energy into the DTV antenna. However, normally the relative position and orientation of the antennas will be arbitrary. The DTV antenna will be placed and presumably oriented to maximize DTV reception. The LTE UE will be used at a location of the user's choosing and quite possibly be in motion, both moving and changing orientation during a conversation. It must be assumed that the coupling between these antennas will be arbitrary and have an equal probability to be in any possible relative position and orientation.

In this discussion orientation refers to the degree to which the antennas are aligned or misaligned. For any given position the LTE UE can be rotated to be aligned for maximum (worst case) coupling to the indoor DTV receiving antenna for a given position and separation distance, or can be aligned to be cross-polarized and have significantly reduced coupling. For antennas of the type used for indoor reception of a DTV signal and LTE UE devices the minimum impact of orientation is 0 dB of isolation, meaning aligned for best possible reception at that position and there is no loss due to misalignment. Theoretically if the antennas are cross polarized there will be no coupling and the misalignment will be large. However, in actuality all antennas have some physical aspect in the orthogonal direction and while a null may be deep is it never perfect. In the calcuations provided later in this section a mean alignment coupling loss of 3.9 dB will be used.

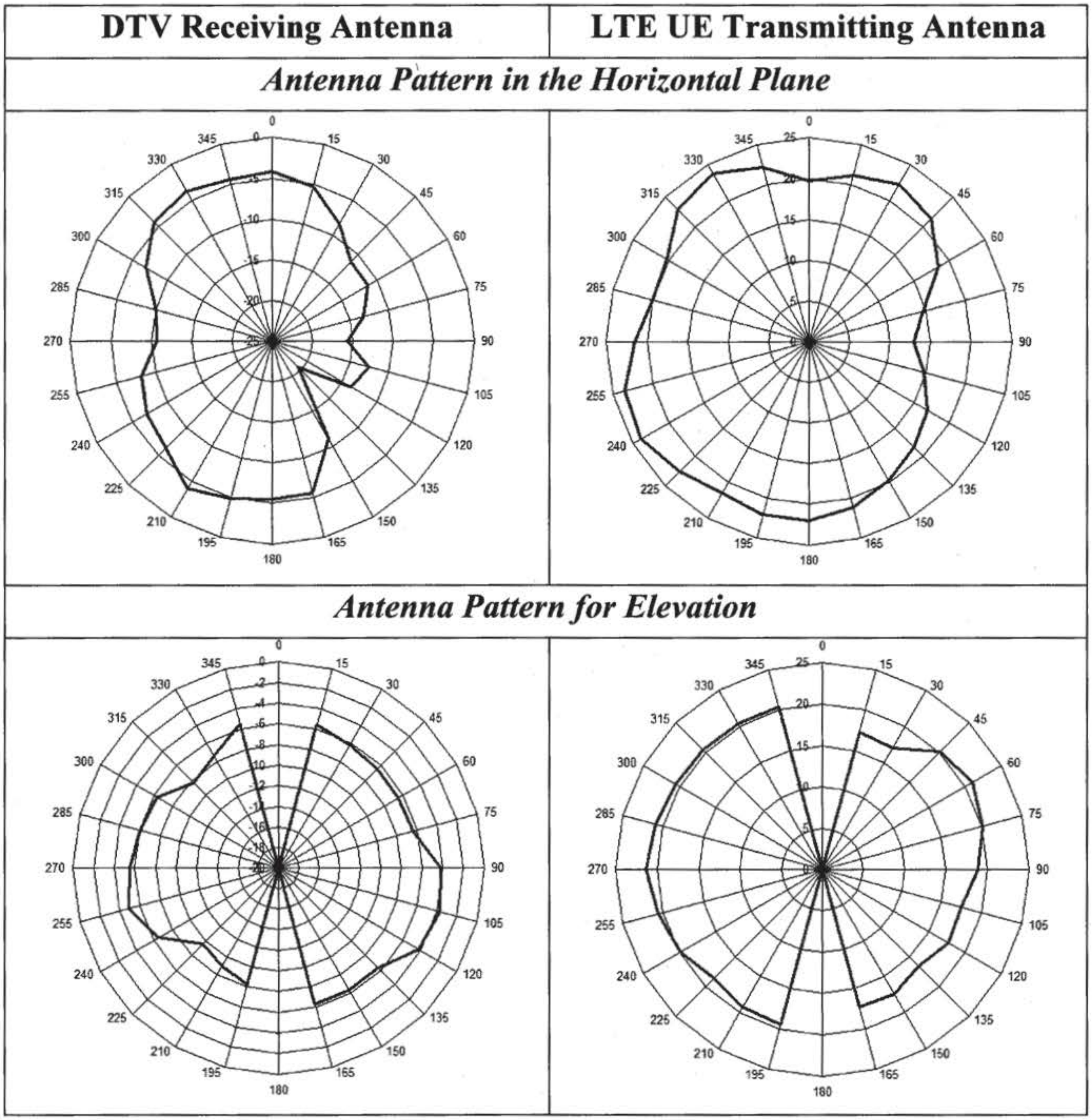

Figure 39 – Variation in relative placement can influence the coupling efficiency between an LTE UE and DTV antenna.

A calculation was performed of the coverage levels for a DTV and UE antenna used in a significant number of the measurements made. While worst case coupling between antennas is clearly possible, additional coupling loss will be present most of the time.

9.3 Calculating coverage levels

The relative position of two antennas (rabbit ear and LTE UE) will add loss to the LTE UE signal received by DTV receivers. The higher the loss the lower the interference the DTV receiver will be experienced. In other words, LTE UEs can operate closer to the DTV receiver before it will interfere with DTV. There are several steps required to calculate the coverage level. Standard statistical 98 PERCENTILE was utilized to calculate the coverage level. At the end, a ratio is calculated from the coverage level calculation. This ratio will be a multiplier to the worst case to acquire the new TOV distance. Since 98 PERCENTILE is used, that means the TOV distance will represent 98% of the times TOV distance will be lower and only 2% of the times the TOV distance will be great. But the TOV distance will not exceed the worst case TOV distance. Here are steps to calculate the additional loss in dB:

1. Create loss matrix from TRP testing (rabbit ear and LTE UE)
   a. 275x275 loss matrix
2. Calculate the Minimum Value (X) of these 275x275 loss matrix
3. Calculate the 98 PERCENTILE Value (Y) for the loss matrix
   a. 98 PERCENTILE value present 98% of the loss will be below and 2% of the loss will be above
4. Calculate Delta Value by (Z) by subtract the 98 PERCENTILE value from the Minimum Value (Z = X-Y)
5. Include the polarization mismatch of 2.06 dB (W = Z - 2.06dB)
6. Calculated the delta distance:

$$20 * \log(\frac{d_1}{d_2})$$

   where

   d_1 = *worst case distance*

   d_2 = *new distance*

7. Calculate the multiplier ratio of change:

$$\frac{New\ Distance - Old\ Distance}{Old\ Distance}$$

The multiplier ratio based on all 12 sets of antenna is listed in Table 29.

Table 29 – Coverage levels shown as in terms of the fraction of the maximum for the 12 combinations tested

Antenna Combination	Percentile
	97.75%
BANDRICH C525 vs GE Enhance	0.45
BANDRICH C525 vs Generic	0.53
BANDRICH C525 vs RCA Flat	0.54
BANDRICH C525 vs RCA1	0.53
BANDRICH C525 vs RCA2	0.58
BANDRICH C525 vs Zenith	0.49
SAMSUNG R930 vs GE Enhance	0.45
SAMSUNG R930 vs Generic	0.54
SAMSUNG R930 vs RCA Flat	0.54
SAMSUNG R930 vs RCA1	0.54
SAMSUNG R930 vs RCA2	0.59
SAMSUNG R930 vs Zenith	0.49

Average	**0.52**
Max	**0.49**
Min	**0.45**

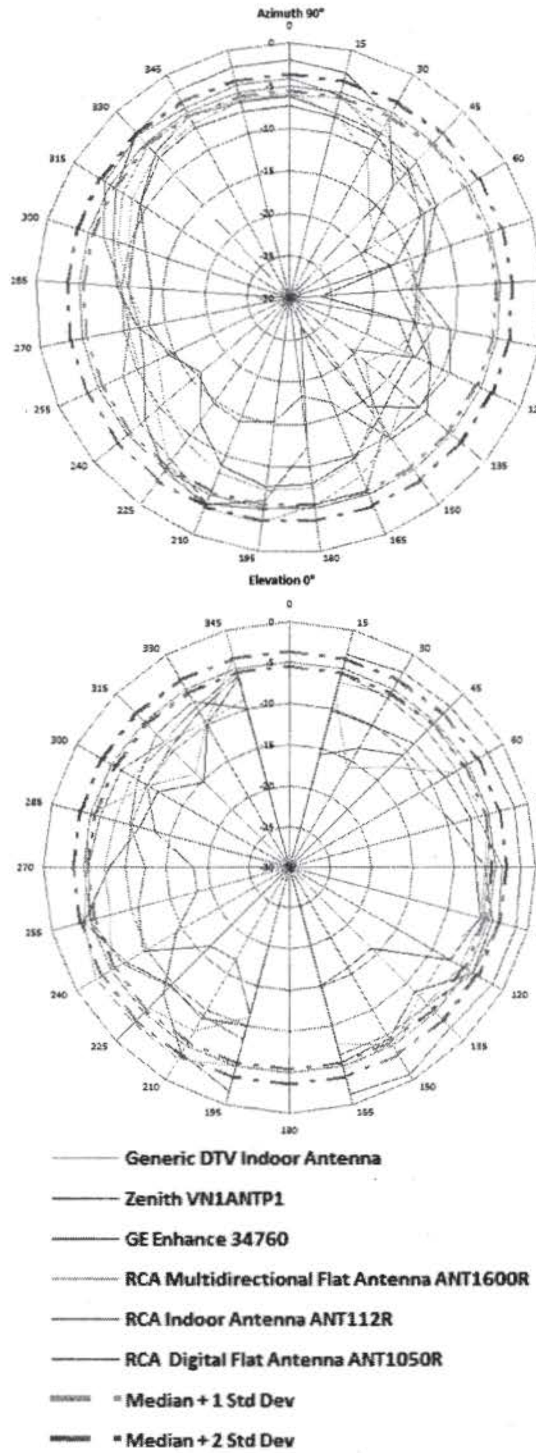

Figure 40 – Plot of DTV receiving antennas with coverage levels shown

9.4 Phone Usage

Usage of cell phones has increased dramatically in recent years, both in the number of people using cell phones and the amount and purposes of use[25]. In the United States in 2007, 82% of adults owned a cell phone of some type, an increase from the 32% in 1999[26]. As of June of 2011, there have become more active mobile devices in the United States than there are citizens[27,28]. According to CTIA there are 331 million cell phones in the U.S., which is 104.6% of the population[29]. Two out of every three Americans own a cell phone, including children and many own multiple phones[30]. This percentage is consistent worldwide, where approximately 5.1 billion people own a cell phone of the 7.1 billion people in the world.[31]

Although the number of active cell phones in the US has grown exponentially, the length of phone calls is relatively short, averaging 3 minutes 15 seconds.[32] According to the United States Department of Labor, the average American spends 0.73 hours per day on the phone, with females spending 0.78 hours on average and males 0.66. This typically comes to 753 minutes per month for females and 525 minutes per month for males.[33,34] Most people receive 5 calls per day and make 5 calls per day as well.[35]

The majority of time spent on the phone coincided with the individual driving. [36,37] For this study these trends create two distinct use cases, driving and non-driving use of cell phones. The implication for home or office interference to DTV is that phones are used less in those environments and so the average amount of time a phone is likely to be in use near a DTV is less than would be expected by looking at average phone use. The second environment is the vehicle environment, where mobile/handheld televisions are increasingly common, often within 2 or 3 feet of the cell phones. In general these televisions are not as susceptible to interference[38] as standard televisions. For this study the station DTV and in-vehicle mobile/handheld DTV are sufficiently distinct as to justify separate consideration.

Overall, cell phones are becoming the most frequently accessed technology in America today. The time recorded above is not factoring in text messages, listening to music, searching the Internet, or using apps – all of which would add to the amount of time that the average American is on their phone. There is research by several foundations that suggests that the average person checks their phone in a range from 34 to 150 times per day.[39,40,41]

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25 Pew Interest and American Life Project. "Cell Phones and American Adults": http://www.pewinternet.org/Reports/2010/Cell-Phones-and-American-Adults/Overview.aspx

26 Elert, Glenn. *The Physics Factbook*. Scarborough Research, 2002.

27 Census.gov, total population for June 2011 in United States

28 The International Association for the Wireless Telecommunications Industry, CTIA. "CTIA Consumer Info". 2012. http://www.ctia.org/consumer_info/index.cfm/AID/10323

29 ibid

30 US Census Bureau. "Steadyrain Presents: Mobile America". July, 2011.

31 Mobile Marketing Association Asia. "Incredible Mobile Marketing Statistics". Digital Utility Team, March 26th 2012. http://www.digitalforreallife.com/tag/mobile-phone-usage-statistics/

32 New York Times. "Drive Time Increasingly Means Talk Time". Bridge Ratings. http://www.nytimes.com/2006/03/06/technology/06drill.html?_r=1&ei=5089&en=d8059507cbdc3ea6&ex=1299301200&adxnnl=1&partner=rssyahoo&emc=rss&adxnnlx=1345572125-fkDLEGI6WB+EMv95NQR0Aw

33 Digital Trends. "New Study Average Teen Sends 3339 Texts Every Month". The Nielson Company, 2010.

34 Mobile Marketing Association Asia. "Incredible Mobile Marketing Statistics". Digital Utility Team, March 26th 2012. http://www.digitalforreallife.com/tag/mobile-phone-usage-statistics/

35 Pew Research Project. "Adult Cell phones Report 2010". Lenhart, Amanda.

36 US Census Bureau. "Steadyrain Presents: Mobile America". July, 2011.

37 United States Department of Labor, Bureau of Labor Statistics. "Economic News Release: Time spent in Primary Activities". 2011 averages. http://www.bls.gov/news.release/atus.nr0.htm

38 Rhodes, Charles. "Cell Phone, DTV Interference Issues Examined". TV Technology

39 Ahonen, Tony. "How Often Do You Check Your Phone". Nokia, MindTrek conference, 2010.

Section 10 Test Equipment & Facilities

#	Test Equipment	Model Number
1	TV Signal Simulator	R&S® SFE DTV Signal Generator
2	LTE UE Control	R&S® CMW-500 Wireless Communications Test Set
3	LTE Waveform Generator	R&S® SMU-B12 LTE Uplink Signal Generator
4	Signal Monitor	R&S® ETL TV analyzer[42]
5	Impedance Adapter	North Hills M/N 0114JA Coaxial Impedance Adapters - 50 to 75 Ω.[43]
6	Coupler	Narda 4226-20
7	RF Amplifier	Mini-Circuits ZHL-4240
8	Tuned Dipoles	ETS-Lindgren 3121

10.1 DTV Antennas

#	Manufacturer	Model Number
1	Zenith	VN1ANTP1
2	GE	Enhance 34760
3	RCA	Multidirectional Flat Antenna ANT1600R

40 Cohen, Elizabeth. "Do You Obsessively Check Your Smartphone?". CNN Report. July 28th, 2010. Accessed August 21st, 2012. pewinternet.org/~/media/Files/Reports/2010/PIP_Adults_Cellphones_Report_2010.pdf

41 Oulasvirta, Antti et al. "Habits Make Smartphone Use More Pervasive". Springer-Verlag, London, 2011.

http://www.hiit.fi/u/oulasvir/scipubs/Oulasvirta_2011_PUC_HabitsMakeSmartphoneUseMorePervasive.pdf

42 The R&S® ETL TV analyzer is primarily used as a spectrum analyzer to monitor the input signal to the DTV receiver's. The R&S® ETL TV analyzer stands for all-in-one. The R&S® ETL combines the functionality of a TV and FM (radio) signal analyzer, a video and MPEG TS analyzer and a spectrum analyzer in a single instrument. The R&S® ETL also contains generators to create analog video signals, audio signals and MPEG-2 transport streams. This instrument is capable of a number of measurements. More information is available at:

http://www.rohde-schwarz.us/product/ETL.html

43 http://www.northhills-sp.com/pdf/products-wb-coaxial-adapters.pdf

4	RCA	Indoor Antenna ANT112R
5	RCA	Digital Flat Antenna ANT1050R
6	Generic	Rabbit Ears Antenna – No label found

10.2 DTV Monitoring

Evaluation of the DTV signal will be performed by observation of the DTV screen by test personnel. The TOV threshold was found to be quite sharp, with the difference between a totally clear picture and a high degree of disruption or even total signal loss occurring within a dB. Hence, using test personnel to determine the threshold was found to be quite practical.

APPENDIX A - List of Acronyms and Abbreviations

Acronym	Definition
BFO	Brute-Force-Overload
dB	Decibel
dBm	Decibels referenced to 1 milliWatt
dBW	Decibels referenced to 1 Watt
D/U ratio	Desired-to-Undesired signal ratio
EUT	Equipment Under Test
FEC	Forward Error Correction
FOM	Figure of Merit
GHz	GigaHertz
ID	Identification
IM	Intermodulation
I/O	Input/Output
IS	Interface Specification
MHz	MegaHertz
Min	Minute
N/A	Not Applicable
OTA	Over-the-Air
PC	Personal Computer
RF	Radio Frequency
Sec	Second
TOS	Threshold of sensitivity
TOS-A	Threshold of sensitivity with signal ascending
TOS-D	Threshold of sensitivity with signal decending
TOV	Threshold of visibility
TOV-A	Threshold of visibility with signal ascending
TOV-D	Threshold of visibility with signal decending
UE	User Equipment

APPENDIX B – Bibliography

Table 30 provides a list of documents which were found useful and provide important background for this project.

Table 30 - Applicable Documents

Document Number	Title	Revision & Date
ATSC A/54A	Recommended Practice: Guide to the Use of the ATSC Digital Television Standard, including Corrigendum No. 1	04 DEC 2003 Cor No 1 20 DEC 2006
ATSC A/64B	ATSC Recommended Practice: Transmission Measurement and Compliance for Digital Television	26 MAY 2008
ATSC A/74:2010	ATSC Recommended Practice: Receiver Performance Guidelines	07 APR 2010
ATSC A/174:2011	ATSC Recommended Practice: Mobile Receiver Performance Guidelines	26 SEP 2011
FCC/OET Bulletin 71	Guidelines for Testing and Verifying the Accuracy of Wireless E911 Location Systems	12 APR 2000
FCC/OET TR 05-1017	Tests of ATSC 8-VSB Reception Performance of Consumer Digital Television Receivers Available in 2005	02 NOV 2005
FCC/OET 07-TR-1003	Interference Rejection Thresholds of Consumer Digital Television Receivers Available in 2005 and 2006	30 MAR 2007
FCC/OET 07-TR-1005	Direct-Pickup Interference Tests of Three Consumer Digital Cable Television Receivers Available in 2005	07 JUL 2007
FCC/OET 9-TR-1003	DTV Converter Box Test Program -- Results and Lessons Learned	09 OCT 2009
IEEE 1900.2-2008	IEEE Recommended Practice for the Analysis of In-Band and Adjacent Band Interference and Coexistence Between Radio Systems	2008
TIA 916	Recommended Minimum Performance Specification for TIA/EIA/IS-801-1 Spread Spectrum Mobile Stations	APR 2002

APPENDIX C – LTE signal specifications

Table 31 – LTE Setup (Handset 5 MHz BW)

PARAMETER	SETTING
Center frequencies	701.5 MHz (5 MHz BW) 702.5 MHz (3 MHz BW) 703.3 MHz (1.4 MHz BW)
Release	3GPP R8
Duplexing	FDD
Modulation	OFDM/OFDMA
Allocation	1 Lower-most RB Freq = 699-704 MHz
RB Bandwidth	180 kHz
UE Power MAX	+23 dBm
Total Radiated Pwr	See individual units
Subcarrier Modulation	QPSK
Dummy Data	PN9

APPENDIX D – Detailed Conducted Test Data

This annex presents the detailed conducted data. The results in this section were obtained using the BandRich Compact LTE USB Modem as the LTE signal source.

When 1 resource block is used, it is placed within the LTE channel as near to the DTV channel as possible.

TOV NR means the Threshold of Visibility was not reached at the highest LTE signal level applied, which was 8 dBm.

It is to be noted that while the Access HD DTA 1080 converter box was tested and those test results are listed in the tables below it was found to be both anomalous and erratic. The sensitivity of this unit was measured to be -63.1 dB, 20 dB worse than the other units in this study and also 20 dB worse that the converter boxes measured by the FCC in FCC OET Report 07-TR-1003, DTV Converter Box Test Program - Results and Lessons Learned, which reported a mean sensitivity of 115 converter boxes measured as being -85.0 dBm and the near worst performance of that group as being -83.6 dBm.[44] This sensitivity would set the TOS + 3 dB level at -60.1 dB, above the -68 dBm test level and far above the TOS +3 dB level of the other units. Testing of this unit at the TOS + 3 dB level yielded erratic results with measurements varying widely, run-to-run. So the unit is recorded as having been tested but no result is provided given the inconsistent and changing results found with the unit.

[44] FCC OET Report 07-TR-1003, DTV Converter Box Test Program - Results and Lessons Learned, Table 2-1.

Table 32 – TOV Levels (LTE UE signal bandwidth 1.4 MHz with 1 Resource Block / DTV Signal at TOS + 3 dB)

Manufacturer	M/N	Description	DTV	DTV TOS+3 dB			
				LTE Signal		D/U Ratio	
			TOS-D	TOV-D	TOV-A	TOV-D	TOV-A
			dBm	dBm	dBm	dB	dB
LG	42LK450	42-Inch 1080p 60 Hz LCD HDTV	-85.7 dBm	-49.2 dBm	-46.2 dBm	-33.5 dB	-36.5 dB
Panasonic	VIERA TC-L32C3	32-Inch 720p LCD HDTV	-84.9 dBm	-44.7 dBm	-44.6 dBm	-37.2 dB	-37.3 dB
Samsung	LN37D550	37-Inch 1080p 60Hz LCD HDTV	-85.2 dBm	-47.6 dBm	-42.8 dBm	-34.6 dB	-39.4 dB
Sony	BRAVIA KDL46NX720	46-inch 1080p WiFi 3D LED HDTV	-84.8 dBm	-48.5 dBm	-44.6 dBm	-33.3 dB	-37.2 dB
Toshiba	24SL410U	24-Inch 1080p 60 Hz LED-LCD HDTV	-83.6 dBm	-37.7 dBm	-35.7 dBm	-42.9 dB	-44.9 dB
Vizio	E220VA	22" Class Edge Lit Razor LED LCD HDTV	-85.6 dBm	-37.7 dBm	-36.6 dBm	-44.9 dB	-46.0 dB
Samsung	UN19D4003	19" 720p 60Hz LED HDTV (Black)	-82.9 dBm	-45.4 dBm	-41.5 dBm	-34.5 dB	-38.4 dB
LG	42CS560	42" Class / 1080p / 60Hz / LCD HDTV	-85.7 dBm	-50.2 dBm	-45.3 dBm	-32.5 dB	-37.4 dB
Samsung	UN32EH4000	32" 720p 60 Hz LED HDTV	-85.8 dBm	-48.6 dBm	-45.6 dBm	-34.2 dB	-37.2 dB
Panasonic	VIERA TC-L32E5	32" 1080p Full HD IPS LED-LCD TV	-85.6 dBm	-45.5 dBm	-45.6 dBm	-37.1 dB	-37.0 dB
LG	47LK520	47" 1080p 120 Hz LCD HDTV	-85.9 dBm	-46.5 dBm	-45.4 dBm	-36.4 dB	-37.5 dB
Samsung	PN43E450	43" 720p 600 Hz Plasma HDTV (Black)	-85.5 dBm	-48.5 dBm	-45.8 dBm	-34.0 dB	-36.7 dB
Samsung	UN32EH5300	32" 1080p 60 Hz LED HDTV (Black)	-85.8 dBm	-48.6 dBm	-45.7 dBm	-34.2 dB	-37.1 dB
Sony	BRAVIA KDL32BX330	32" 720p HDTV, Black	-82.9 dBm	-37.3 dBm	-35.4 dBm	-42.6 dB	-44.5 dB
Toshiba	24V4210U	24" 1080P/60HZ LED DVD Combo	-84.0 dBm	-42.9 dBm	-42.8 dBm	-38.1 dB	-38.2 dB
VIZIO	E3D320VX	32" Class Theater 3D LCD HDTV	-85.8 dBm	-32.8 dBm	-33.7 dBm	-50.0 dB	-49.1 dB
Sharp	LC46SV49U	46" Class - LCD - 1080p - 60Hz - HDTV	-86.2 dBm	-48.4 dBm	-45.4 dBm	-34.8 dB	-37.8 dB
Insignia	NS-19E320A13	19" Class / LED / 720p / 60Hz / HDTV	-81.3 dBm	-47.4 dBm	-43.8 dBm	-30.9 dB	-34.5 dB
RCA	26LA33RQ	26" Class / 720p / 60Hz / LCD HDTV	-85.5 dBm	-47.2 dBm	-44.3 dBm	-35.3 dB	-38.2 dB
Haier	L32D1120	32" 720p LCD HDTV, Black	-85.4 dBm	-46.3 dBm	-45.2 dBm	-36.1 dB	-37.2 dB
JVC	LT19E610	19" LED-LCD TV - 16:9 - HDTV	-85.7 dBm	-47.4 dBm	-46.4 dBm	-35.3 dB	-36.3 dB
Coby	TF-TV1212	12" TFT-LCD Monitor with TV Tuner	-84.4 dBm	-48.3 dBm	-45.3 dBm	-33.1 dB	-36.1 dB
Access HD	DTA1080	DTV converter box	-63.1 dBm	inconsistent	inconsistent	inconsistent	inconsistent
Sansonic	FT-300A	DTV converter box	-83.0 dBm	-38.7 dBm	-36.7 dBm	-41.3 dB	-43.3 dB
Jensen	JDTV-1020	10" TFT Color LCD TV	-82.1 dBm	-31.7 dBm	-32.7 dBm	-47.4 dB	-46.4 dB
Vizio	VMB070	7" LED Portable TV	-83.7 dBm	-37.8 dBm	-42.6 dBm	-42.9 dB	-38.1 dB
		Minimum	-86.2 dBm		-50.2 dBm		-50.0 dB
		Maximum	-63.1 dBm		-31.7 dBm		-30.9 dB
		LTE UE signal is 1.4 MHz bandwidth centered at 703.3 MHz with 1 RB					